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SPACE BASE ANTENNA STUDY

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GODDARD SPACE FLIGHT CENTER
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SPACE BASE ANTENNA STUDY

Leonard F. Deerkoski
Network Engineering Division

March 1971

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

ILLUSTRATIONS (Continued)

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SPACE BASE ANTENNA STUDY

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ABSTRACT

The field of view required of the Space Base Antenna is defined for both the Tracking and Data Relay Satellite link and Detached Module links. The gain requirements are established and the feasibility of alternative antenna configurations using phased arrays and reflectors are considered. One recommended and one alternative configuration are presented for each of the required links. The Space Base design recommended by North American Rockwell in their Phase B definition of the Space Station Program was used as a guide for this antenna study.

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SPACE BASE ANTENNA STUDY

I. INTRODUCTION

During the one year period ending August 1970, NASA funded parallel studies by North American Rockwell [1] and McDonnell Douglas [2] for Phase B study of the Space Station Program. This program initially included a requirement for an artificial gravity experiment. For long duration space travel, the need for continuous artificial gravity was established and the Space Station evolved into the Space Base (SB) which inherently includes both zero "G" and artificial "G" segments.

The requirement for continual artificial gravity poses significant problems for the SB communication links. North American Rockwell included a section in its Space Station Study devoted exclusively to Space Base Definition. The Space Base Definition included no detailed analysis of the field of view or antenna system requirements. This report is intended to answer these questions based upon the data available and SB configuration recommended in the North American Space Base Definition report.

This report is organized to first define the communications requirements of the SB, then to present alternative antenna configuration to meet these requirements and finally, to recommend the most practical antenna system.

II. COMMUNICATION REQUIREMENTS

The SB communication links with TDRS and the DMs are completely independent. Each link will be considered separately but a composite antenna system meeting all communication requirements is recommended later in the report.

A. TDRS Link (Full Duplex)

Bandwidth:	100 MHz
SNR (at receiver):	+17 db (10^{-6} BER, 4 db margin)
Frequency:	13.7-15 GHz
TDRS antenna gain:	+46 db (1.8 meter dish)
Transmit power:	10 watts
TDRS altitude:	41,800 km (synchronous)
TDRS Orbit Inclination:	0 rad
Number of TDRS:	2 minimum
SB Altitude:	505 km
SB Orbit Inclination:	$11\pi/36$ rad

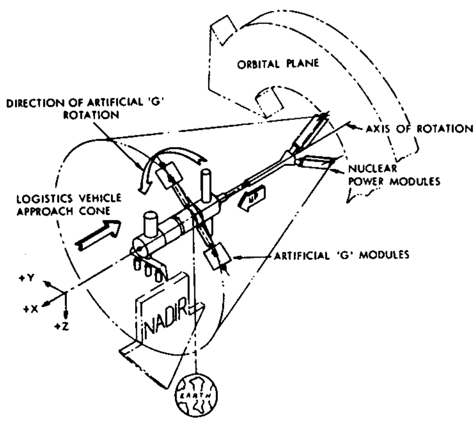
Link calculations for maximum slant range are given in Table 1. The required gain is a function of earth angle between TDRS and SB. The earth central angle defines the angle of the TDRS from the -Z axis of the SB. The gain required of the SB antenna is plotted in Figure 1 as a function of TDRS angle from the -Z axis (zenith angle).

The field of view required of the SB antenna for communication with the TDRS can be completely defined in terms of angular position relative to the -Z axis (zenith) and angular position from the +X axis measured about the Z axis (azimuth). (Refer to Figure 1 for definition of coordinate system.) The SB is oriented with its +Z axis pointing towards earth center and X axis perpendicular to its orbital plane (X-POP orientation). The requirement that the SB be in an X-POP orientation imposes a $\pm 11\pi/36$ rad azimuth rotation upon the field of view defined by the SB with its X axis oriented north-south. In order to simplify description of the beam pointing requirements, the $\pm 11\pi/36$ rad azimuth rotation due to the X-POP orientation will be considered after the simpler north-south orientation of the X axis has been completed.

Table 1

Link Calculations Between Space Base and TDRS

	Space Base to TDRS	TDRS to Space Base
Frequency	13.7 - 14.2 GHz	14 - 15 GHz
Bandwidth	100 MHz	100 MHz
RF Power (10 W)	+ 40 dbm	+ 40 dbm
TDRS Antenna Gain (1.8m dish)	+ 46 db	+ 46 db
Max. Space Attenuation (48,200 km)	-210 db	-210 db
RF Losses	- 2 db	- 2 db
Signal Power at Receiving Antenna	-126 dbm	-126 dbm
Noise Power (100 MHz BW)	- 92.5 dbm (T_S = 500K)	- 95.5 dbm (T_S = 250K)
Required SNR (10^{-6} BER)	+ 13 db	+ 13 db
Margin	+ 4 db	+ 4 db
Required Space Base Gain	+ 50.2 db	+ 47.5 db



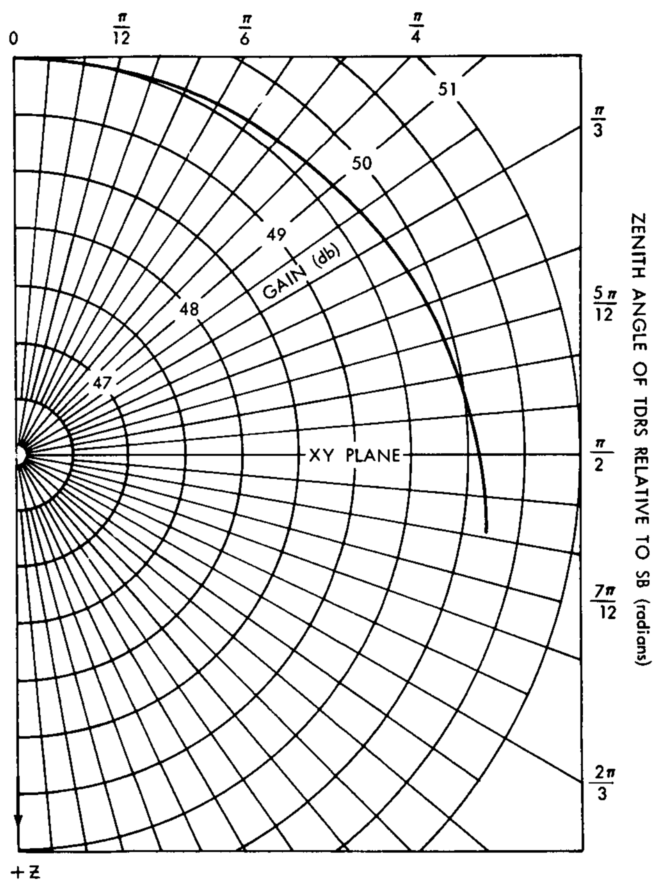


Figure 1. Required Gain of Space Base Antenna Vs Zenith Angle of TDRS

The minimum azimuth angle of the TDRS relative to the ±X axis of the SB is plotted in Figure 2 as a function of relative longitude for several SB orbit inclinations. The shaded area in this figure represents the range of azimuth beam

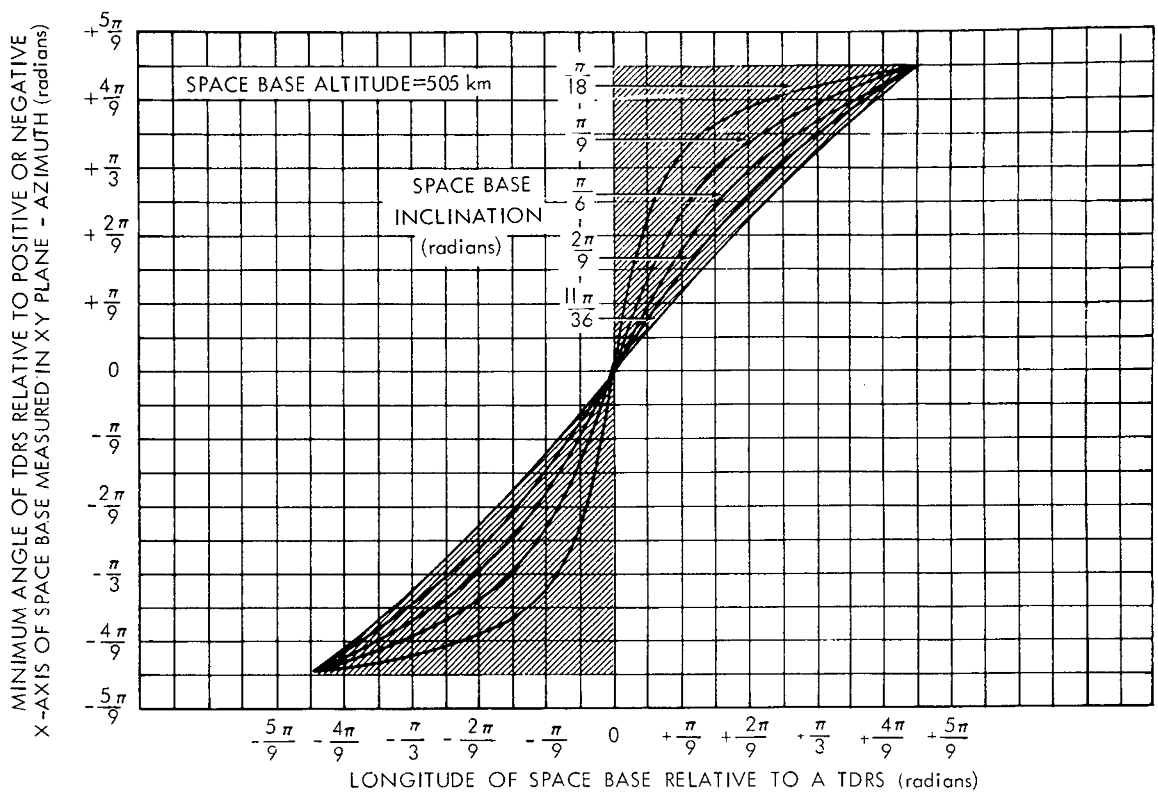


Figure 2. Azimuth of TDRS Vs Relative Longitude for Several Space Base Orbit Inclinations

steering for a $11\pi/36$ rad inclination. The maximum zenith angle of the TDRS is plotted in Figure 3 for several SB orbit inclinations. The shaded area again represents the range of zenith beam steering for $11\pi/36$ rad SB orbit inclination. Plotting zenith angle vs azimuth, the field of view of the TDRS is plotted in Figure 4. A three dimensional illustration of the beam pointing requirement is shown in Figure 5 by the shaded cap. Figures 4 and 5 assume communication from SB to a TDRS within $\pm\pi/2$ radians relative longitude which is the required coverage for a two TDRS system. For a three TDRS system with $2\pi/3$ rad angular separation, the required SB antenna field of view is shown in Figure 6.

The use of a gimbaled reflector antenna requires knowledge of the apparent angular velocity of the TDRS. The velocity will vary as the SB orbital plane

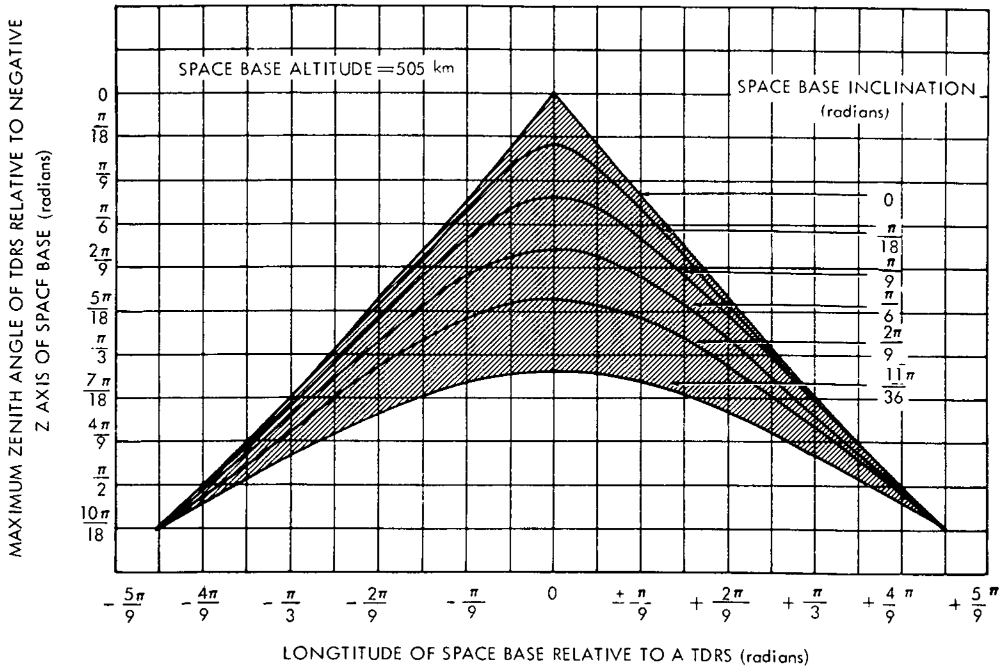


Figure 3. Maximum Zenith Angle of TDRS Vs Relative Longitude for Several Space Base Orbit Inclinations

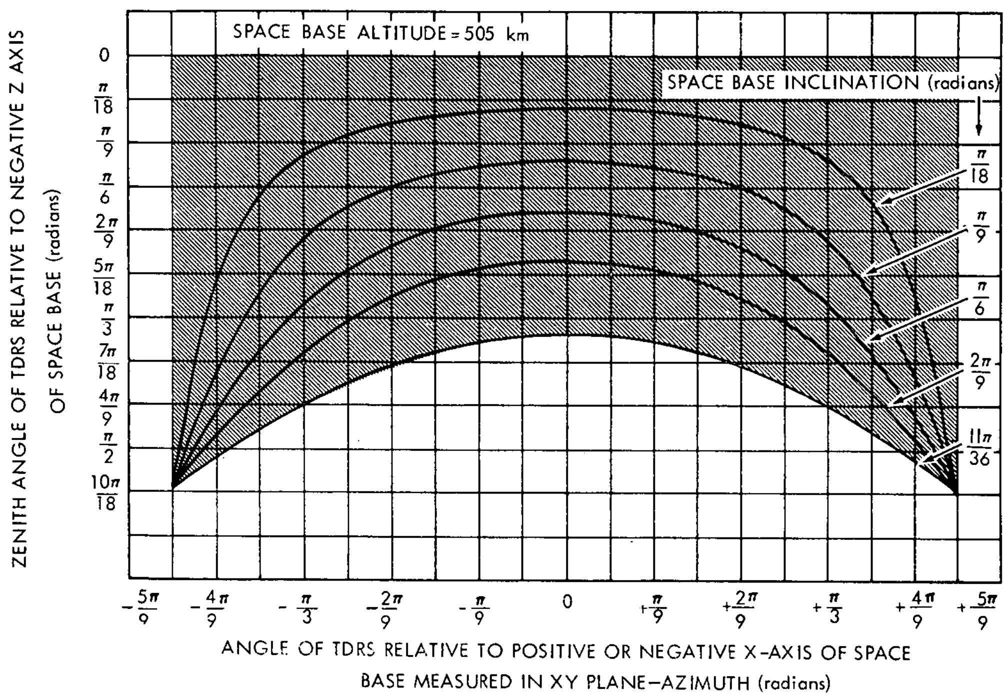


Figure 4. Required Azimuth Vs Zenith Angle Field of View for the Space Base Antenna for Communication with TDRS

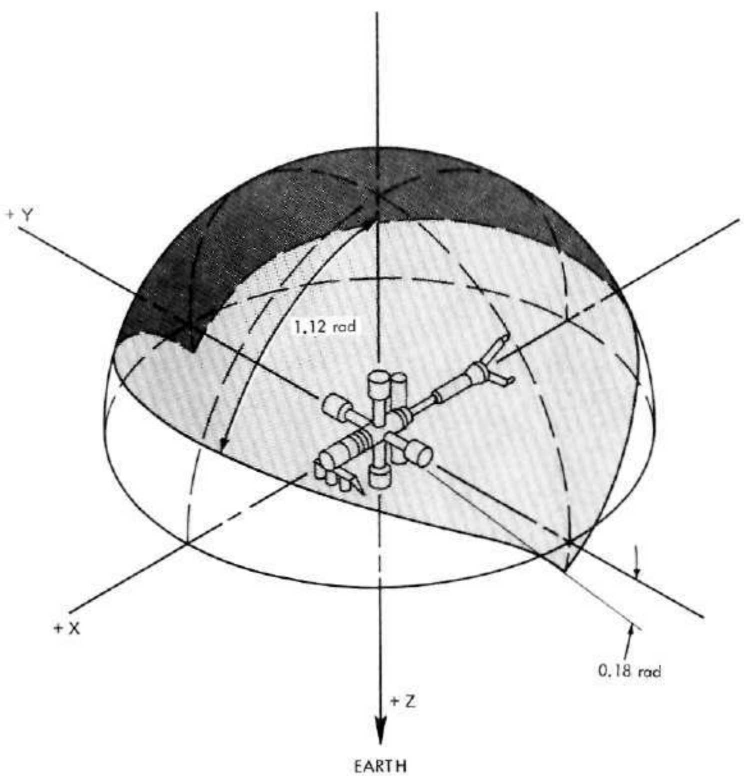


Figure 5. Required Space Antenna Field of View for Communication with TDRS, Assuming a Two TDRS Syatem and Y Axis Parallel to Equatorial Plane

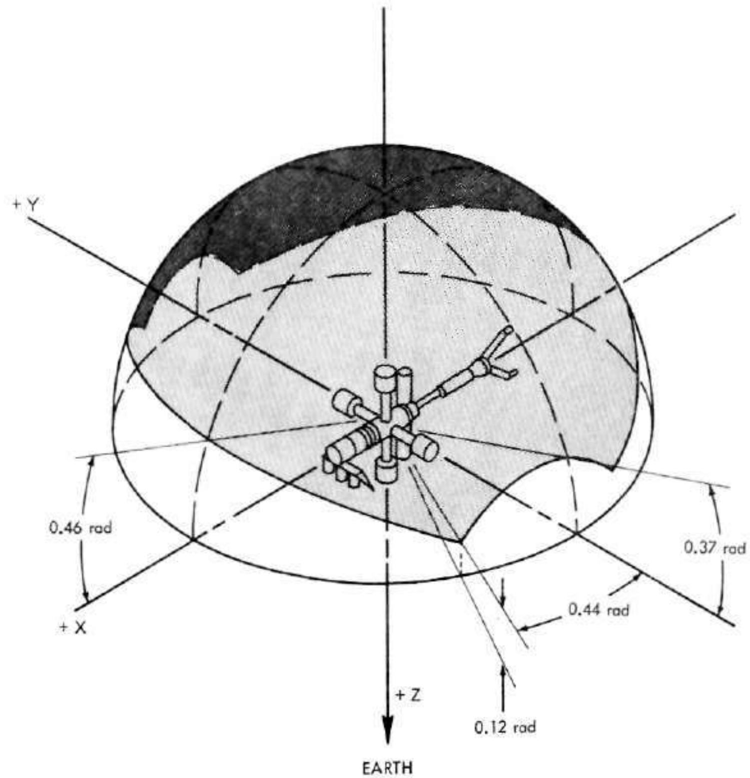


Figure 6. Required Space Base Antenna Field of View for TDRS Link in a Three TDRS System, Y Axis of Space Base Parallel to Equatorial Plane

processes about the earth. Figures 7 and 8 represent the azimuth and elevation angular velocities for several precession angles (γ). The tracking of the TDRS at small zenith angles requires azimuth angular velocities which approach a π rad change in zero time. The requirement for zenith tracking demands an XY type gimbal.

Assuming an XY gimbal on the SB with X = 0 rad pointing North and Y = 0 rad pointing East, the angular velocities for each axis are given in Figures 9 and 10. The maximum X velocity is 0.26 mrad/s and the maximum Y velocity is 0.18 mrad/s.

The effect of maintaining an X-POP orientation for a two TDRS system is to rotate the field of view requirement in Figure 5 by $\pm 11\pi/36$ rad about the Z axis. With the exception of a conical region centered on the ±X axis, the communication link with TDRS requires $\pm 10\pi/18$ rad field of view relative to the -Z axis (Figure 11). For a three TDRS system with $2\pi/3$ rad spacing, the X-POP orientation rotates the field of view requirement of Figure 6 $\pm 11\pi/36$ rad about the -Z axis. For this condition the SB antenna must provide coverage for all positions within approximately $8\pi/18$ rad of its -Z axis (Figure 12).

The need for essentially hemispherical coverage by the SB antenna for communications with TDRS makes a gimbaled reflector most attractive.

B. Detached Module (DM) Links

The frequency for the SB to DM communication link has been established only to the extent that it will be 2 GHz or higher. An S-band and a Ku-band link will be analyzed in this section. There are three modes of communication between SB and DM:

Mode 1: High data rate (full duplex) — high gain antenna on SB and on DM.

Mode 2: Monitor (SB receive only) — omni antenna on SB, high gain antenna on DM.

Mode 3: Emergency (full duplex) — high gain antenna on SB and omni antenna on DM.

There will be a maximum of 10 DMs requiring support from the SB. The simultaneous communication requirements are listed below:

Mode	# of DMs (simultaneous)
1	2
2	8

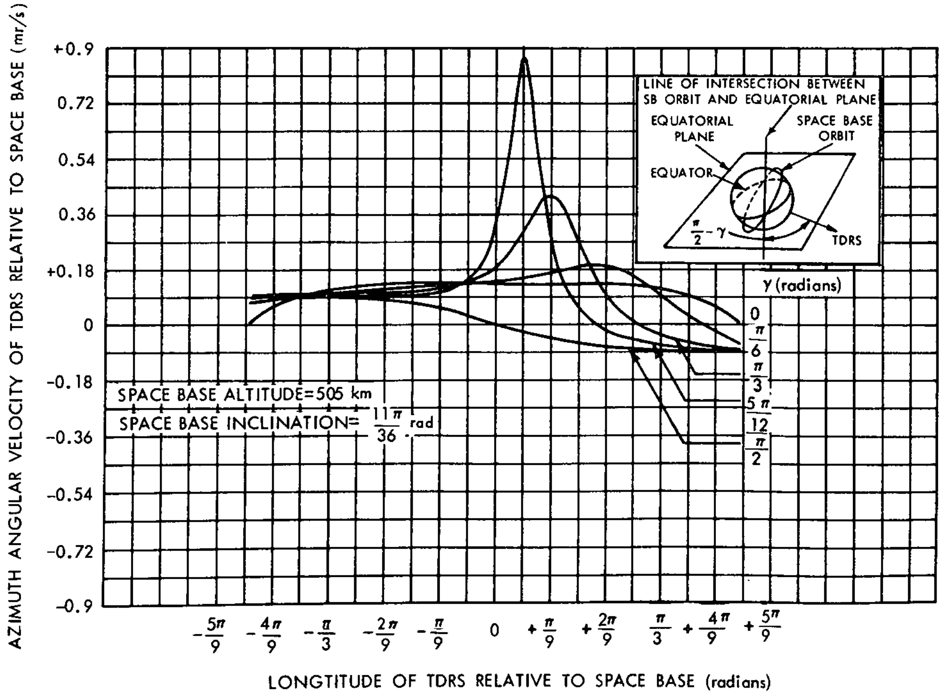


Figure 7. Azimuth Angular Velocity of TDRS Relative to SB

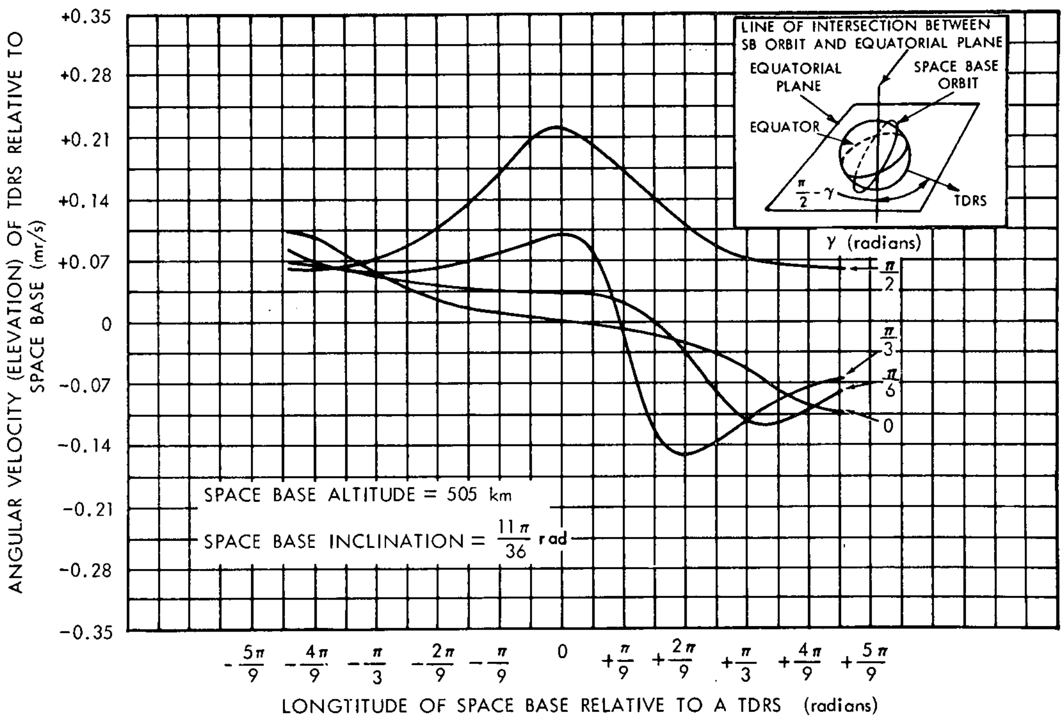


Figure 8. Elevation Angular Velocity of TDRS Relative to SB

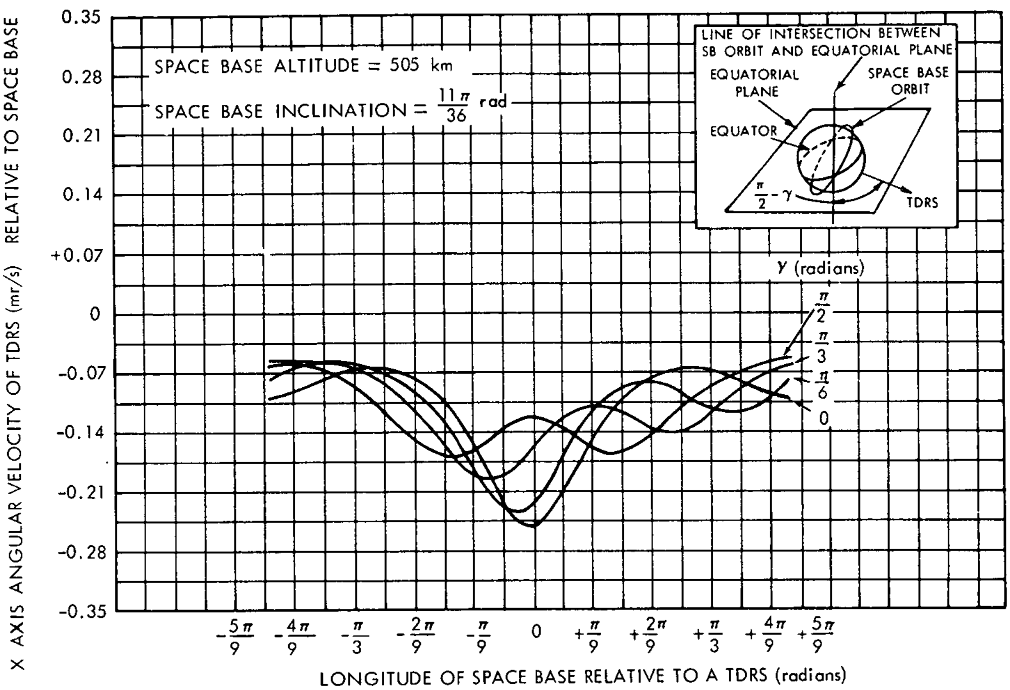


Figure 9. X Axis Angular Velocity of TDRS Relative to SB

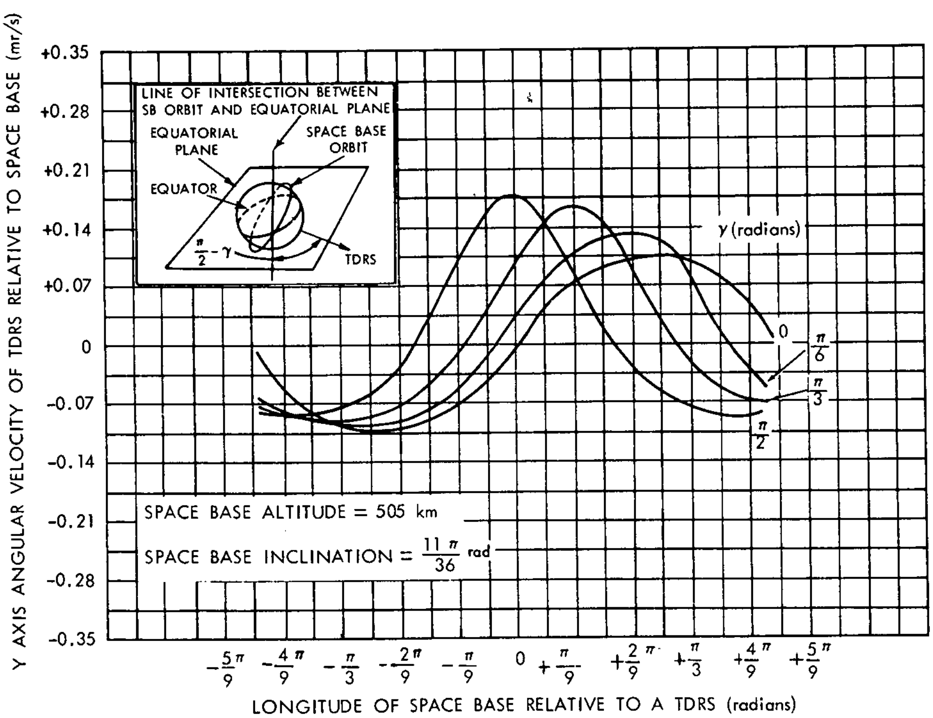


Figure 10. Y Axis Angular Velocity of TDRS Relative to SB

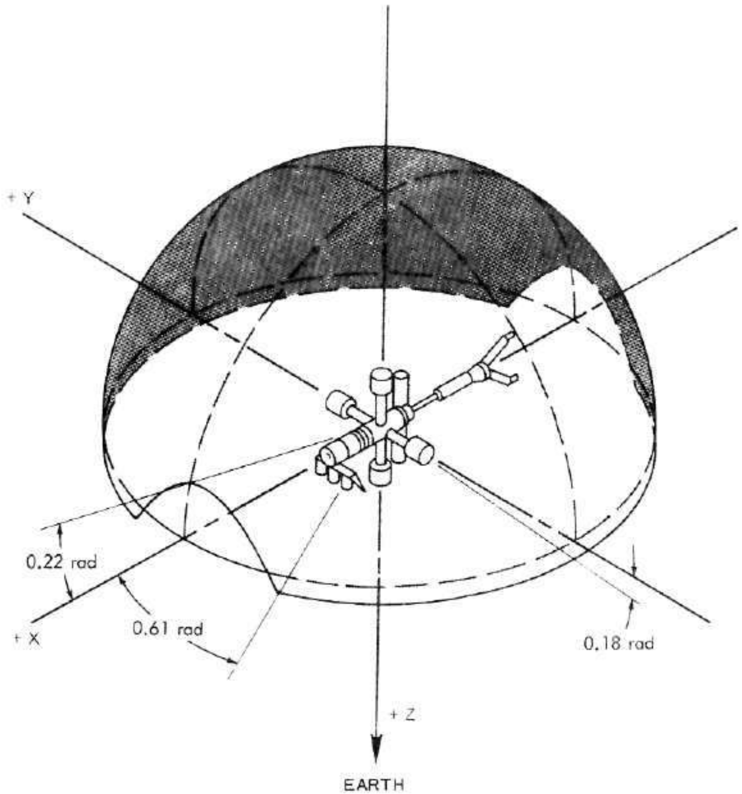


Figure 11. Required Space Base Antenna Field of View for TDRS Link in a Two TDRS System, Space Base in X-POP Orientation

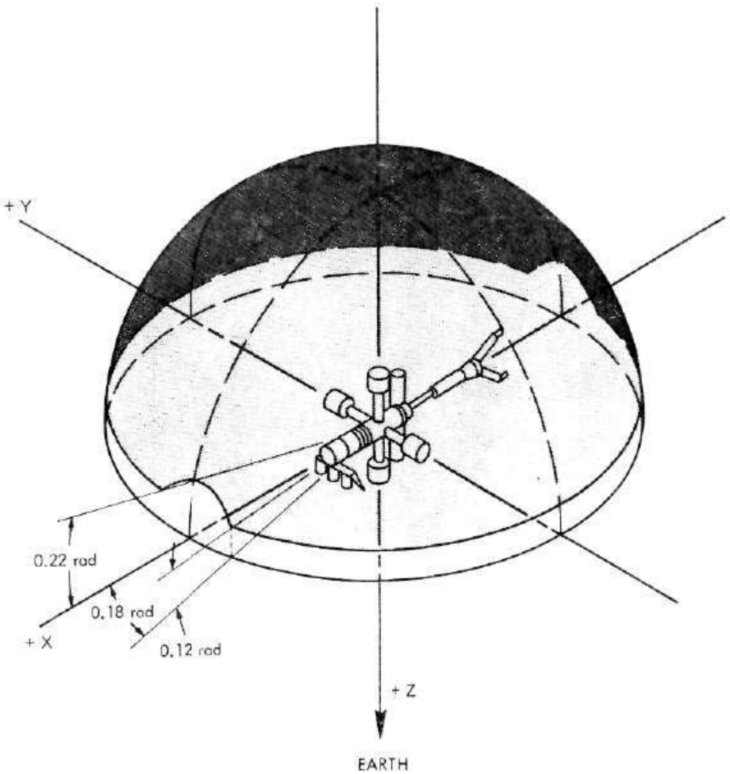


Figure 12. Required Space Base Antenna Field of View for TDRS Link in a Three TDRS System, Space Base in X-POP Orientation

The emergency mode of operation utilizes the high gain SB antenna beam used in normal Mode 1 operation. The position of each DM is restricted to the extent listed below:

Altitude: minimum — 370 km

maximum — 555 km

Maximum earth angle between SB and DM: 0.6 rad

The link calculations for S-band and Ku-band are indicated in Tables 2 and 3 respectively. The DM high gain antenna is assumed area limited and is 0.9 m

Table 2

Link Calculations Between Space Base and Detached Modules (S-Band)

	Mode 1	Mode 2	Mode 3
Frequency	2 GHz	2 GHz	2 GHz
Bandwidth	30 MHz	25 kHz	160 kHz
RF Power (10 W)	+ 40 dbm	+ 40 dbm	+ 40 dbm
DM Antenna Gain (0.9m dish)	23 db	23 db	0 db*
Space Atten. (4620 km)	-172 db	-172 db	-172 db
Misc. RF loss	- 2 db	- 2 db	- 2 db
Signal Power at SB	-111 dbm	-111 dbm	-134 dbm
Noise Power (T_s = 500K)	- 97.5 dbm	-128 dbm	-120.5 dbm
Required SNR (10^{-6} BER, 4 db margin)	+ 17 db	+ 17 db	+ 17 db
Required SB Antenna Gain	30.5 db	0 db	30.5 db

*Omni antenna

diameter for both S-band and Ku-band. In Mode 2 operation, the antenna gain increase at Ku-band over S-band is cancelled by the space attenuation which increases by the same proportion. This mode of operation is therefore independent of frequency.

The Ku-band link is advantageous from the standpoint of Mode 1 operation since the SB effective antenna diameter is 0.9m as opposed to 2m at S-band. However, the higher frequency does impact Mode 3 operation. A 30 kHz bandwidth can be supported at Ku-band using the same SB antenna used for Mode 1, while at S-band a 160 kHz bandwidth can be handled for similar conditions. However, emergency

Table 3

Link Calculations Between Space Base and Detached Modules (Ku-Band)

	Mode 1	Mode 2	Mode 3
Frequency	15 GHz	15 GHz	15 GHz
Bandwidth	20 MHz	25 kHz	30 kHz
RF Power (10 W)	+ 40 dbm	+ 40 dbm	+ 40 dbm
DM Antenna Gain (0.9m dish)	+ 40 db	+ 40 db	0 db*
Space Atten. (4620 km)	-189 db	-189 db	-189 db
Misc. RF loss	- 2 db	- 2 db	- 2 db
Signal Power at SB	-111 dbm	-111 dbm	-151 dbm
Noise Power (T_S = 500K)	- 97.5 dbm	-128 dbm	-127.5 dbm
Required SNR (10^{-6} BER, 4 db margin)	+ 17 db	+ 17 db	+ 17 db
Required SB Antenna Gain	40.5 db	0 db	40.5 db

*Omni antenna

voice requires only 5 kHz bandwidth per channel and six voice channels would be available even at Ku-band.

The required SNR of 17 db includes a 4 db margin and assumes PCM/FM modulation. Using quadriphase PSK, the required SNR would be reduced by 2 db. Since the modulation has not yet been defined, PCM/FM was assumed.

The field of view required by the SB antenna for communication with the DMs is spherical. However, the antenna gain is highly dependent upon the angle of the DM relative to the XY plane of the SB. Since the DM is restricted in altitude (370-555 km) and earth central angle (0.6 rad) from the SB, the SB antenna gain relative to the XY plane is symmetrical about the Z axis of the SB. Figure 13 indicates the gain required of the SB antenna for Mode 1 and Mode 3 operation as the DM moves from one extreme position to another.

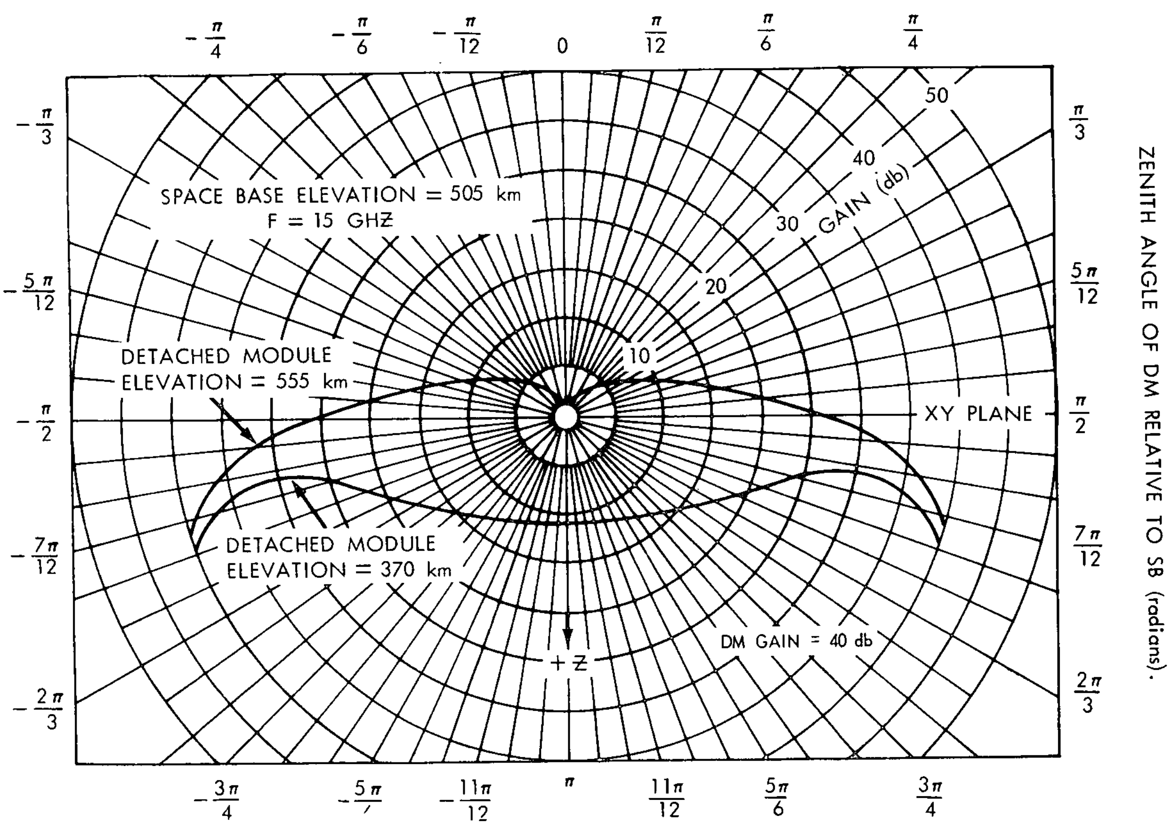


Figure 13. Required Space Base Antenna Gain Vs Position of Detached Module

III. ANTENNA

A. Reflector

The positioning of reflector antennas on the SB in support of the TDRS and DMs is highly dependent on SB geometry. The communication requirements established in Section II for links with TDRS and the DMs are simultaneous and distinct. Therefore the reflector antennas and their positioning will be considered separately for each application.

1. TDRS Link. The 50.2 db gain defined in Table 1 establishes the need for a 3 m reflector antenna (55% efficiency). For a three TDRS system, each $2\pi/3$ rad apart, the required field of view is illustrated in Figure 12. The reflector must be separated from the X-axis of the SB a distance sufficient to prevent blockage by the artificial "G" module. The artificial "G" module has two arms located π r apart, each extending 33 m from the X-axis of the SB (28 m from the outer surface of the Local Vertical Orientation (LVO) segment of the SB).

Single Reflector Configuration — The antenna can be mounted on a tower attached to the LVO segment or to the Inertial Orientation (IO) segment of the SB. If the tower is attached to the LVO segment, the required tower height is a function of location relative to the artificial "G" module. With the center of the tower 3 m from a docked DM, the tower height must be at least 24.5 m (Figure 14). When

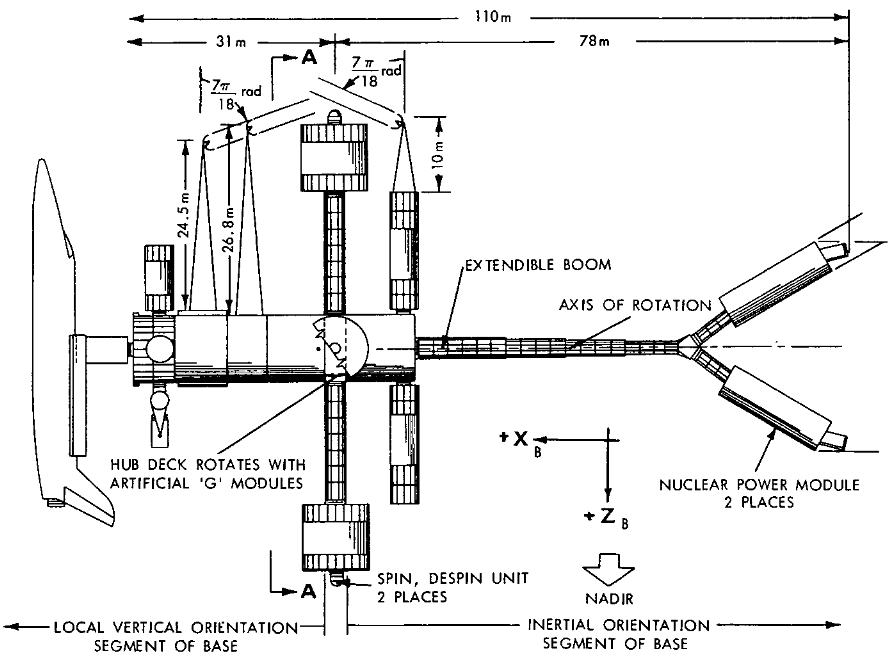


Figure 14. Location of Space Base Reflector Antenna for Communication with TDRS

the tower is centered between the artificial "G" module and DM docking port, the minimum tower height is 26.8 m.

Since the DMs routinely use their docking ports, locating the tower close to the docking area poses a safety hazard to the DM crew. Bringing the tower closer to the artificial "G" module reduces the hazard but requires a tower height approximately equivalent to that of the rotating sections.

A third alternative involves mounting the tower to the Attached Module (AM) oriented along the -Z axis. The required tower height is 10 m. The AMs are docked early in the buildup sequence of the SB and are in place prior to initial spin-up of the artificial "G" module. The AMs are docked to the SB once and remain permanently attached. Mounting the antenna and tower on the AM has several advantages:

a. The tower shown attached to the AM in Figure 14 could be an extendable boom similar to that used for the nuclear power modules. An extendable boom could simplify deployment of the tower and significantly reduce volume requirements for logistics purposes.

b. The antenna and tower are separated from the DM docking ports by the artificial "G" module. The tower is located 10 m from the rotating section and imposes little obstruction for DM operations beyond that already due to the rotating section.

c. The spin/despin jets at the extremity of the artificial "G" module fire normal to the X axis of the SB and therefore are not affected by the antenna.

The required and available field of view for a 3 m reflector on a 10 m tower attached to the AM (Figure 14) is indicated in Figure 15. This configuration provides adequate field of view for a three TDRS system with $2\pi/3$ rad separation between spacecraft. For a two TDRS system a 14 m tower height is required.

The antenna was not considered for mounting on the extendable boom of the nuclear power modules for several reasons:

a. The required tower height is similar to that for mounting on the LVO segment of the SB and is at least twice that required for mounting on the AM.

b. Mounting the tower on the extendable boom will complicate the boom mechanism.

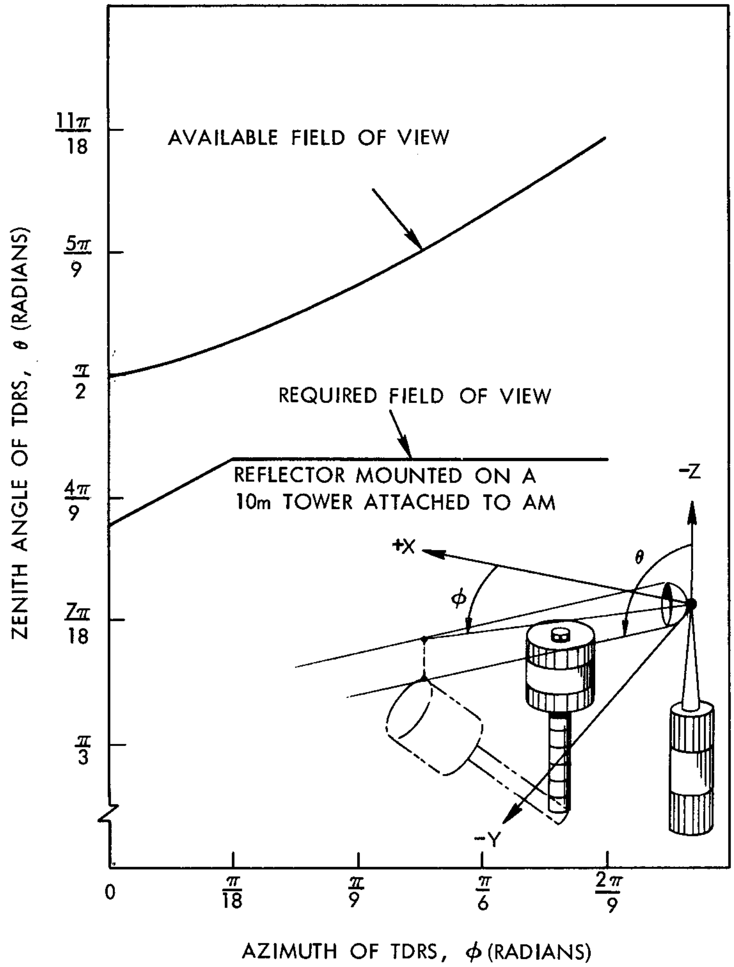


Figure 15. Field of View of SB Antenna for Communication with TDRS

c. The nuclear power sources pose a radiation hazard to the electronics of the antenna.

As described in Section II, the reflector would have an XY type gimbal with the lower axis of rotation oriented along the Y axis of the SB. The noise temperature of the antenna is a combination of cosmic noise and spillover of the primary reflector illumination onto the earth. Cosmic noise is less than 10K at Ku-band and is therefore minimal. The terrestrial noise temperature is 254K. Noise temperature contribution due to spillover onto earth can be minimized by using a cassegrain feed system for the antenna.

A two axis gimbal similar to that required for the reflector is currently under development by Ball Brothers, Inc. for the TDRE antenna on NIMBUS E. Assuming

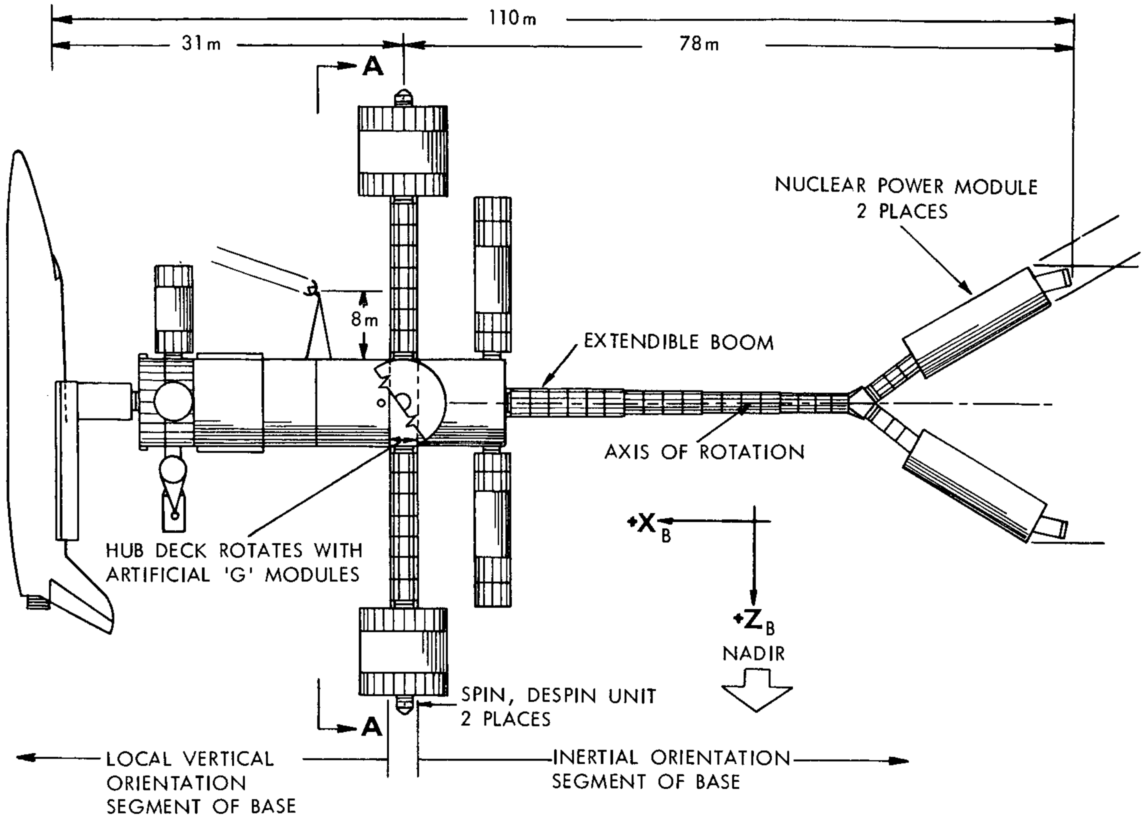


Figure 16. Location of a Reflector for Providing Partial Field of View for TDRS Communications

a SB antenna weight of 23 kg, the two axis gimbal would weigh approximately 12 kg. The 1 db beamwidth of the antenna is 5.2 mrad. The maximum angular velocity of the TDRS relative to the SB is 0.26 mrad/s. This relatively low angular velocity, as compared to antenna beamwidth, makes a digitally controlled gimbal feasible. The NIMBUS TDRE gimbal has 1.75 mrad steps and ±0.35 mrad accuracy. Such a gimbal arrangement would need to be updated at a maximum rate of 1/7s for the SB application. By increasing the step increment to 3.5 mrad (adequate for maintaining pointing accuracy sufficient for keeping within 1 db BW), the maximum rate would be 1/14s.

Although a two axis gimbal has not yet been flown, single axis gimbals on Orbiting Solar Observatory spacecraft have operated in the space environment for more than four years. The gimbaled reflector is therefore a technically feasible alternative for the SB to TDRS communication link.

The requirement for an uninterrupted link between SB and TDRS necessitates two reflectors to cover the handover period. Both reflectors would be mounted on the AM in place of the single reflector shown in Figure 14.

Multi-Reflector Configuration — If the reflector cannot be mounted on the AM as described in the previous section, the artificial "G" module blockage can be avoided by using a multi-reflector system. For the required field of view on the LVO side of the plane defined by the rotating artificial "G" module, a single reflector mounted on an 8 m tower is sufficient (Figure 16).

The remaining field of view can be provided with two additional reflectors (Figure 17) mounted on towers approximately 3 m in height. Two are required to overcome the blockage caused by the AM extending in the -Z direction. A three

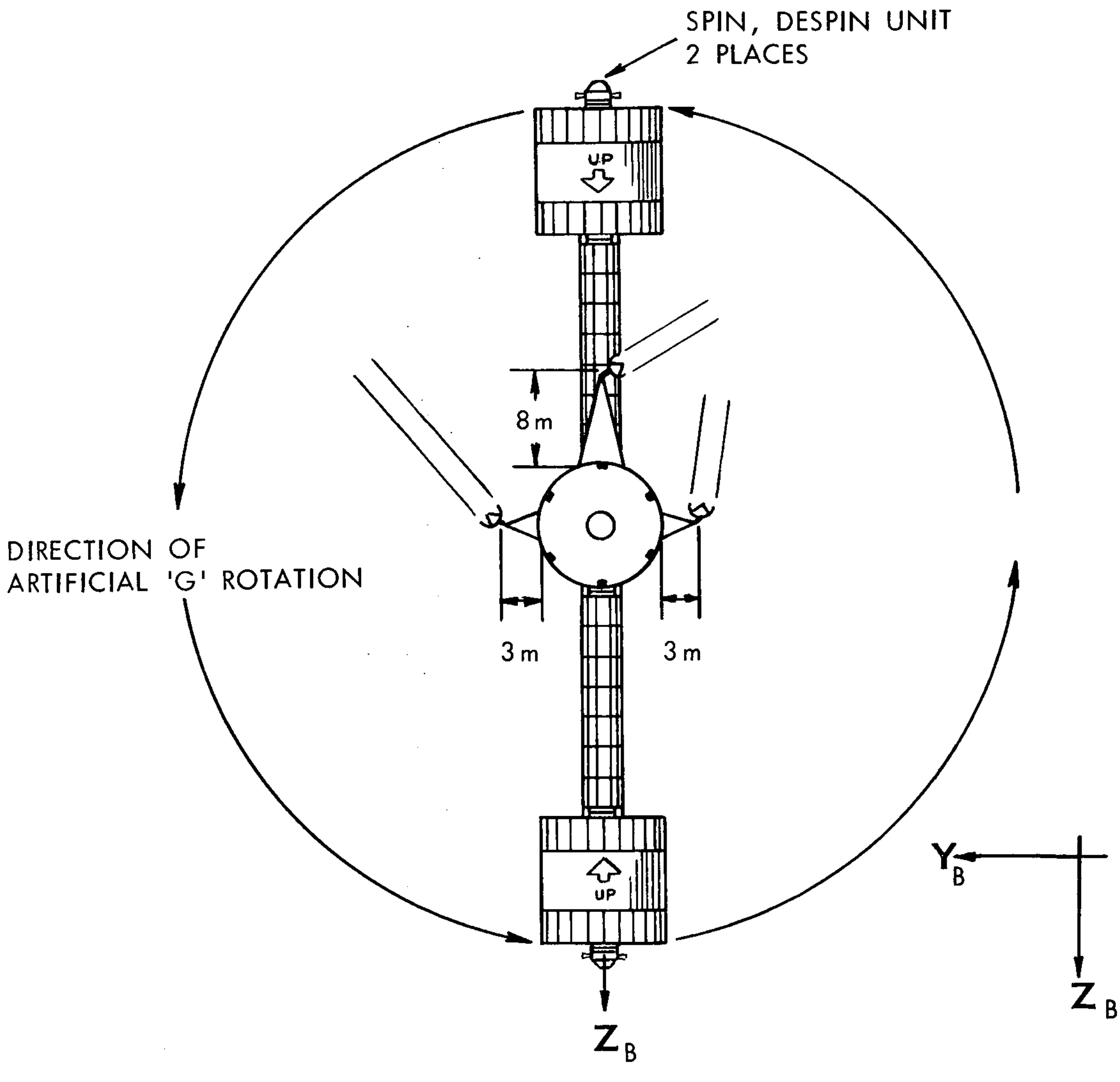


Figure 17. Reflector Arrangement for Complete Field of View for TDRS Communications

dimensional illustration of the system is shown in Figure 18. The reflectors and gimbals for each of these antennas would be identical to that required of the single reflector case.

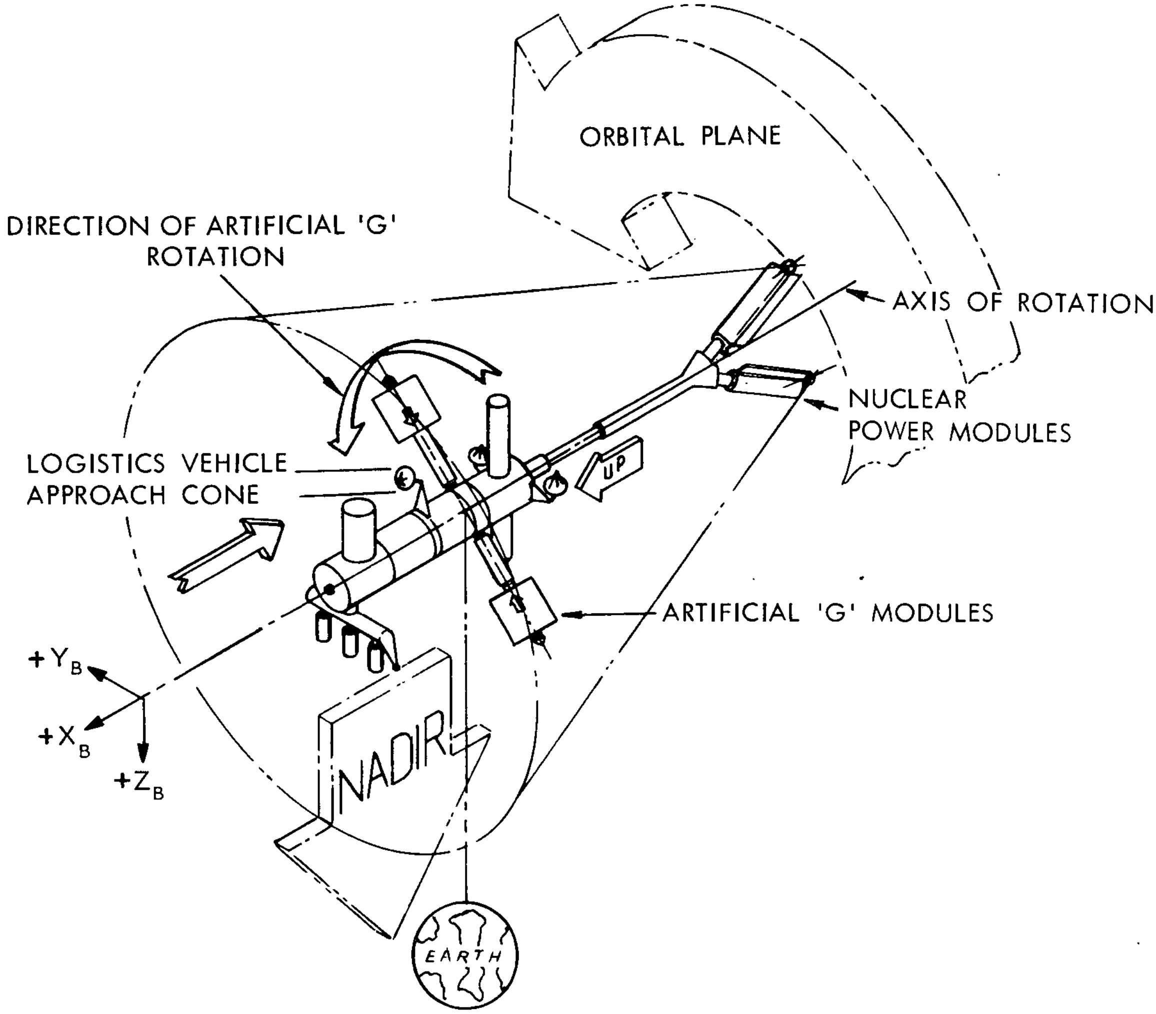


Figure 18. Three Dimensional Illustration of Reflector Antenna System for TDRS Communications

The two antennas mounted on the IO segment of the SB can be replaced by a single antenna mounted on a tower extending in the -X direction (Figure 19). The required tower height is seven meters.

In order to provide uninterrupted communication during handover periods, two independent antennas must be available on each side of the artificial "G" section.

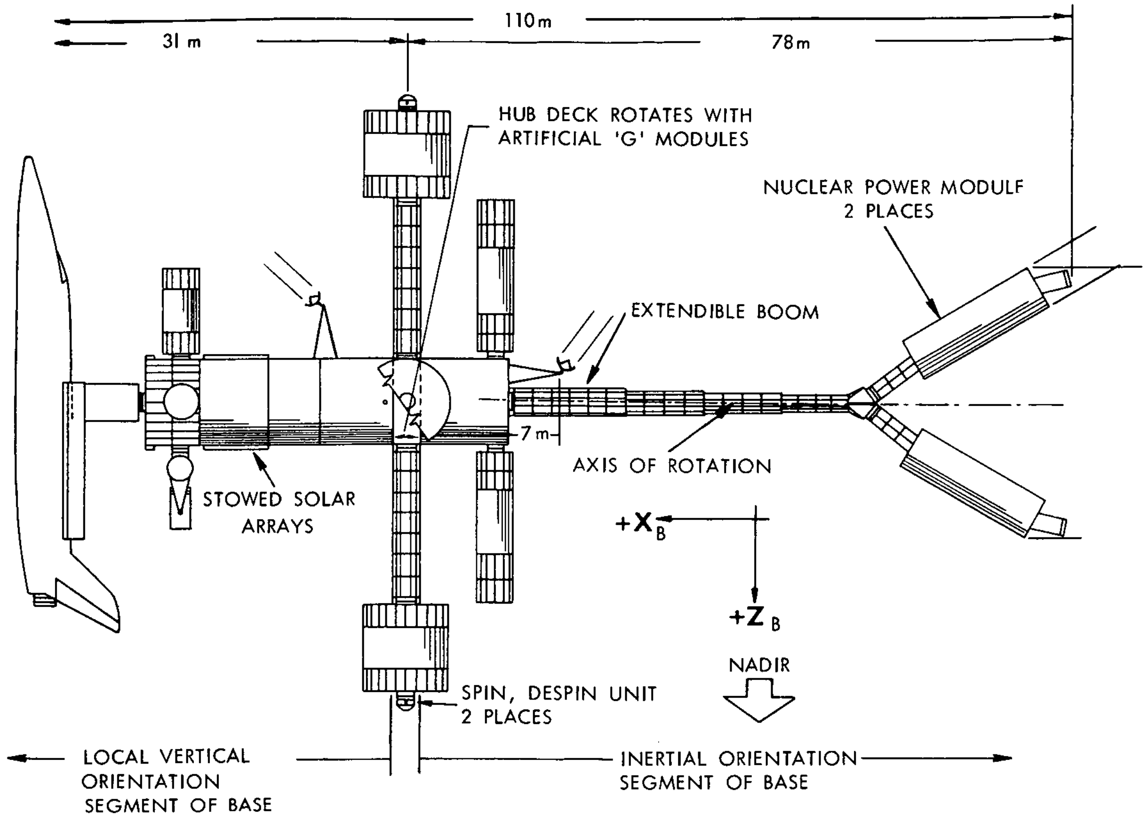


Figure 19. Alternate Reflector Antenna System for TDRS Communications

For the configuration of Figure 17, the only change necessary is to replace the single antenna mounted on the LVO section with two independent antennas. For the configuration of Figure 19, each of the antennas would need to be replaced by two independent antennas.

2. Detached Module Links. Unlike the gain required for communication with TDRS, which is essentially constant over the required field of view, the gain requirement for the DMs is highly dependent on position (Figure 13). The required field of view is spherical. The gain required above the XY plane of the SB in Figure 13 does not exceed 26 db. Below the XY plane the maximum gain is 40 db. Two high gain beams are required simultaneously for Mode 1 operation. The shape of the required gain curve is compatible with the gain capability of cylindrical arrays. This possibility will be discussed in the next section. This section will discuss the alternative antenna configuration using only reflector antennas.

If the reflectors are mounted on towers attached to the body of the SB, a minimum of four biaxially gimbaled reflectors (0.9 m diameter) would be required on the LVO segment to cover the hemisphere on the LVO side of the plane defined by the artificial "G" modules. Four additional reflectors are required to provide hemispherical coverage on the IO side of the artificial "G" module. This requirement of eight antennas can be reduced to four if the antennas are mounted on extensions to the AMs as in Figure 20. The reflectors mounted on the AM extending along the +Z axis would be 0.9 m diameter, those on the -Z axis would be 0.2 m diameter.

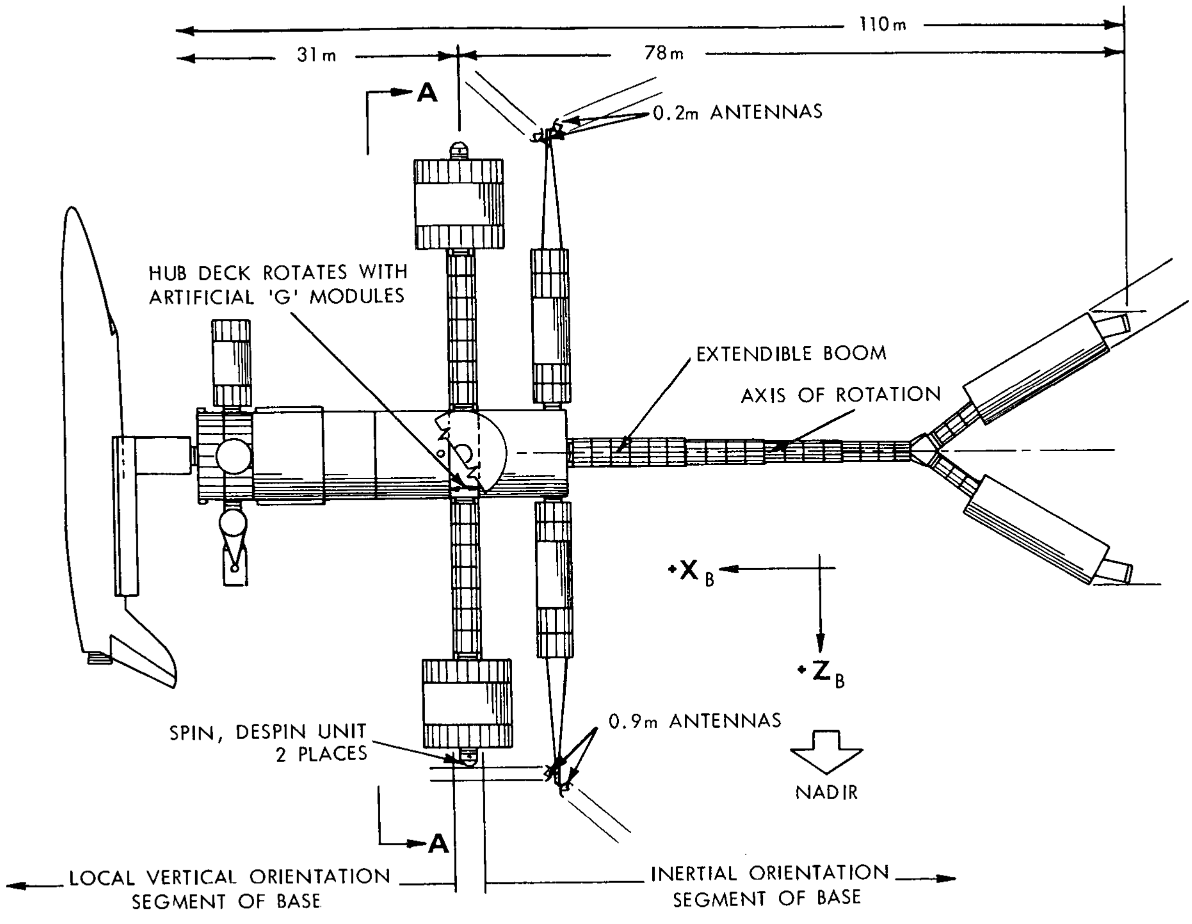


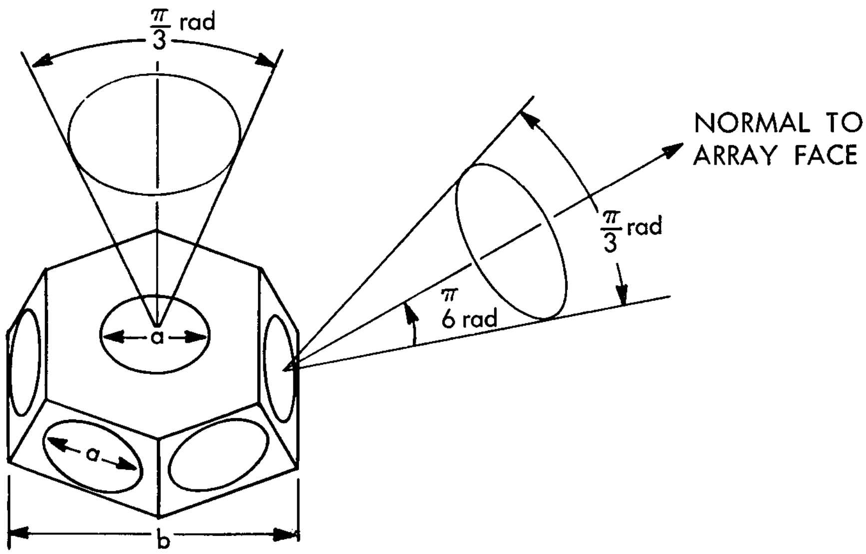
Figure 20. Gimbaled Antenna System for Communication with Detached Modules

The omni antenna requirements (Mode 2 operation) for the DM links will require an array of low gain elements to provide spherical coverage. These elements can be mounted in numerous configurations. The simplest of these is to place the low gain antennas on the extensions to the AMs. In this way, the blockage due to the spacecraft is avoided by requiring hemispherical coverage only from each AM location.

B. Arrays

The purpose of this section is to consider the feasibility of inertialess beam-steering to meet the SB communication requirements. This approach eliminates the need for mechanically gimbaled antennas entirely. A hybrid scheme using a combination of mechanical gimbal and phased array offers no significant advantage since biaxial gimbal drives can now provide sufficient tracking accuracy for the TDRS link and reasonably good reliability for the SB lifetime requirement of 10 years.

1. TDRS Link. The simplest phased array scheme for meeting the TDRS link requirements is shown in Figure 21. Each of the seven faces of the array must



FRONT END	REQUIRED GAIN EACH ARRAY	a	b
PARAMETRIC AMPLIFIER	53 db	4.1 m	10.4 m
TUNNEL DIODE AMPLIFIER	56.5 db	6 m	15.2 m

Figure 21. Antenna System in Support of TDRS Communications

provide 53 db gain which includes a 3 db margin above that listed in Table 1 to compensate for the crossover loss. The link calculations in Table 1 assume a 250K system noise temperature (with no terrestrial noise contribution). The Goddard Space Flight Center now has under development a space qualified Ku-band uncooled parametric amplifier with 150K noise temperature. The amplifier includes a self-contained pump. The entire package occupies 98.5 cm^3 and weighs 1.25 kg. Five watts of power are required. The state of the art in space qualified tunnel diode amplifiers is 6 db at Ku-band. This additional noise figure must be compensated with an additional antenna gain of 3.5 db over that shown in Table 1. The required antenna gain is therefore 56.5 db with a tunnel diode amplifier front end. A two stage tunnel diode amplifier weighs 0.34 kg and draws 0.3 w (plus power for temperature control). A weight and power summary of the front end only of the antenna system shown in Figure 21 is listed in Table 4 for both parametric and tunnel diode amplifier front ends. Figure 22 indicates the relative size of the array while positioned on an extension to the AM.

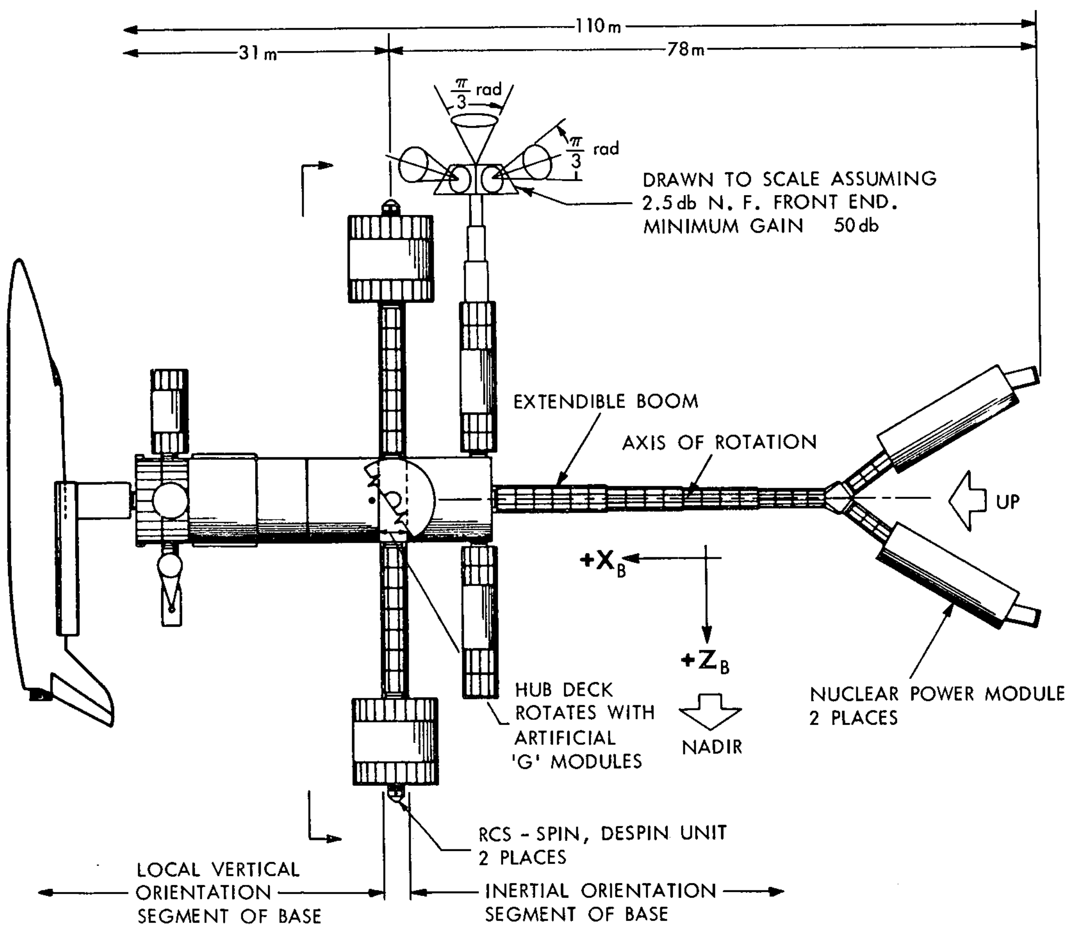


Figure 22. Stationary Array System in Support of TDRS

Table 4

Front End Weight and Power, Phased Array Antenna System In Support of TDRS Communications

Type of Front End Electronics	N.F.	Weight per Element	Power Per Element	No. Elements Required Per Antenna	Weight Per Antenna	Power Per Antenna	Total Weight of Array
Parametric Amplifier	2.5 db	1.24 kg	5 W	31,600	39,200 kg	158 kW*	222,000 kg*
Tunnel Diode	6 db	0.34 kg	0.3 W	72,800	24,700 kg	21.8 kW*	173,000 kg*

*These are best estimates of weight and power which may be in error by an order of magnitude. However, this is sufficient accuracy for the purpose of tradeoff against reflector antennas in this report.

The weight and power of the front end for a corporate feed array as indicated in Table 4 makes such a system unfeasible. The disadvantages of corporate fed arrays can be reduced with reflectarrays in which only one low noise front end is required. Although reflectarrays offer significant potential advantage, further development is necessary before the weight and power consumption for this technique make it competitive with reflectors.

Conformal arrays were not considered in detail for the following reasons:

a. An array conformal to the main body of the SB cannot provide the required field of view.

b. Since gain is a function of projected area, a conformal array will be less efficient than that shown in Figure 21 and the disadvantages of power and weight already discussed will be increased.

2. Detached Module Links. As in the case of the reflector antenna, the field of view required for DM communications can be broken into two segments. However, for the array the lower segment will consist of that area greater than $5\pi/12$ rad from the -Z axis of the SB, the upper segment will consist of the remaining field of view. A possible antenna system is shown in Figure 23.

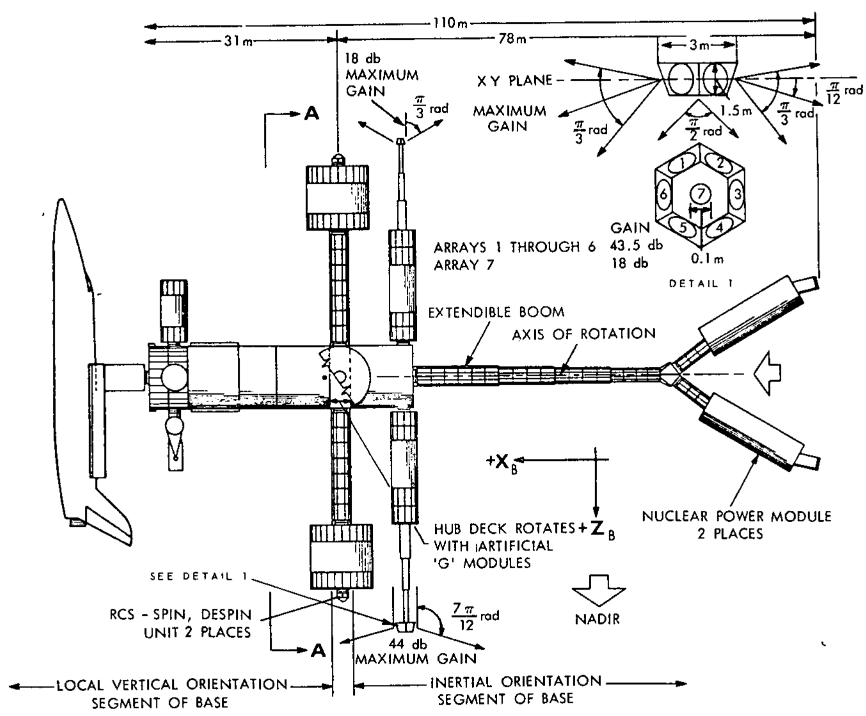


Figure 23. Stationary Array System in Support of Detached Modules

The array mounted on an extension to the AM extending in the +Z direction will be considered first. Assuming 8 db gain per element, the crossover loss is 3 db. With a 2.5 db NF front end, 44 db antenna gain is required from faces 1 through 6. A weight and power summary for the front end of the array is shown in Table 5 for both parametric and tunnel diode amplifiers. Array face 7 provides scan capability within a 90° cone centered on the +Z axis. At the extreme scan angles, 14 db gain is required (Figure 13). A 10 element array of 8 db gain elements will provide 18 db maximum gain and 14 db at the maximum scan angles as required. The weight and power consumption of this array is insignificant in comparison to that of faces 1 through 6.

Table 5

Front End Weight and Power, Lower Segment of DM Communication Link

Type of Front End Electronics	Front End N.F.	Weight Per Element	Power Per Element	No. Elements Required Per Antenna	Weight Per Antenna	Power Per Antenna	Total Weight Array (faces 1-6)
Parametric Amplifier	2.5 db	1.24 kg	5 W	4,000	30,000 kg	20 kW*	180,000 kg*
Tunnel Diode	6 db	0.34 kg	0.3 W	9,200	3,120 kg	2.8 kW*	18,700 kg*

*These are best estimates of weight and power which may be in error by an order of magnitude. However, this is sufficient accuracy for the purpose of tradeoff against reflector antennas in this report.

The array for the upper field of view segment as shown in Figure 23 is also a six facet array. The normal to each array face makes a $\pi/3$ rad angle with the -Z axis. Each array must provide 18 db gain with 2.5 db NF front ends to maintain 15 db gain at crossover. The weight and power summary for this antenna system is shown in Table 6.

Table 6

Front End Weight and Power, Upper Segment of DM Communication Link

Type of Front End Electronics	Front End N.F.	Weight Per Element	Power Per Element	No. Elements Required Per Antenna	Weight Per Antenna	Power Per Antenna	Total Weight of System (6 faces)
Parametric Amplifier	2.5 db	1.24 kg	5 W	10	12.4 kg	50 W	74.5 kg
Tunnel Diode	6 db	0.34 kg	0.3 W	23	7.8 kg	7 W	46.8 kg

Conformal arrays were not considered in detail for the DM links for the same reasons discussed earlier for the TDRS link.

IV. RECOMMENDATIONS

A. TDRS Link

The size, weight and power of a stationary phased array on the SB for communication with TDRS precludes the feasibility of this alternative. Although a biaxial gimbal capable of handling a 3 m reflector system has not been flown the technology is within the current state of the art. The reflector can be fed with a monopulse feed to provide closed loop tracking of the TDRS.

Mounting the reflector on an extension to the AM as in Figure 24 presents minimum impact to the SB, requiring only a single reflector for complete TDRS coverage. This alternative is the recommended antenna system for TDRS communication. If handover blackout periods are unacceptable a second reflector mounted adjacent to the first must be added.

If the antenna cannot be mounted on an extension to the AM, the configuration shown in Figure 25 is recommended. A minimum of three identical biaxially gimbaled reflectors are required. The advantage of this configuration over that shown in Figure 19 is that the two reflectors mounted along the Y axis of the SB are attached at points uncluttered by other mechanisms, whereas in Figure 19 the AM, the nuclear power source boom and the antenna are located in close proximity.

B. DM Links

The lower segment of the DM communication link presents the same disadvantages for a corporate fed phased array as did the TDRS link (Table 5). Two biaxially gimbaled 0.9 m reflectors mounted on an extension to the AM along the +Z axis is the recommended antenna configuration for the lower segment DM link requirement (Figure 24). The need for positioning the antennas beyond the extremity of the artificial "G" module is more important for this DM link than that for TDRS since $\pm 7\pi/12$ rad coverage relative to the +Z axis is required by the lower segment antennas.

The upper segment DM requirement can be accomplished with either phased arrays or reflectors. The array offers rapid beam steering, a feature that is compatible with the time sharing of the two high gain beams (mode 1 operation) between DMs. Although the gimbaled reflector requires less volume and power for equivalent gain capability and field of view, the size of the six facet array shown in Figure 23 is already relatively small and can fit within a 0.5 m cylinder. The phased array is more compatible with the TDRS antenna which is also mounted on the same AM. As shown in Figure 24, the DM array antenna facets can be distributed around a light weight platform which eliminates blockage by

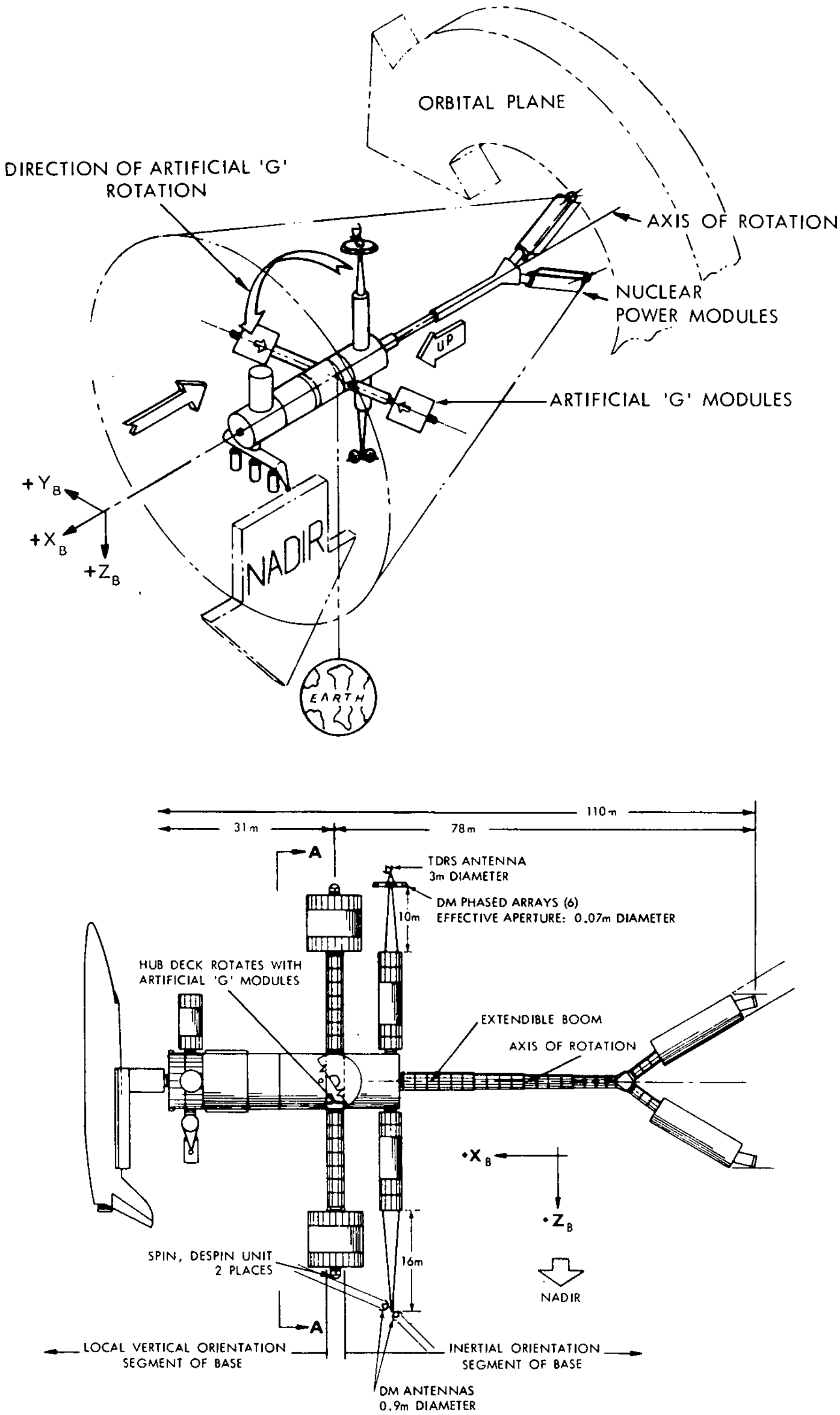


Figure 24. Recommended SB Antenna System for Communication with TDRS and DMs

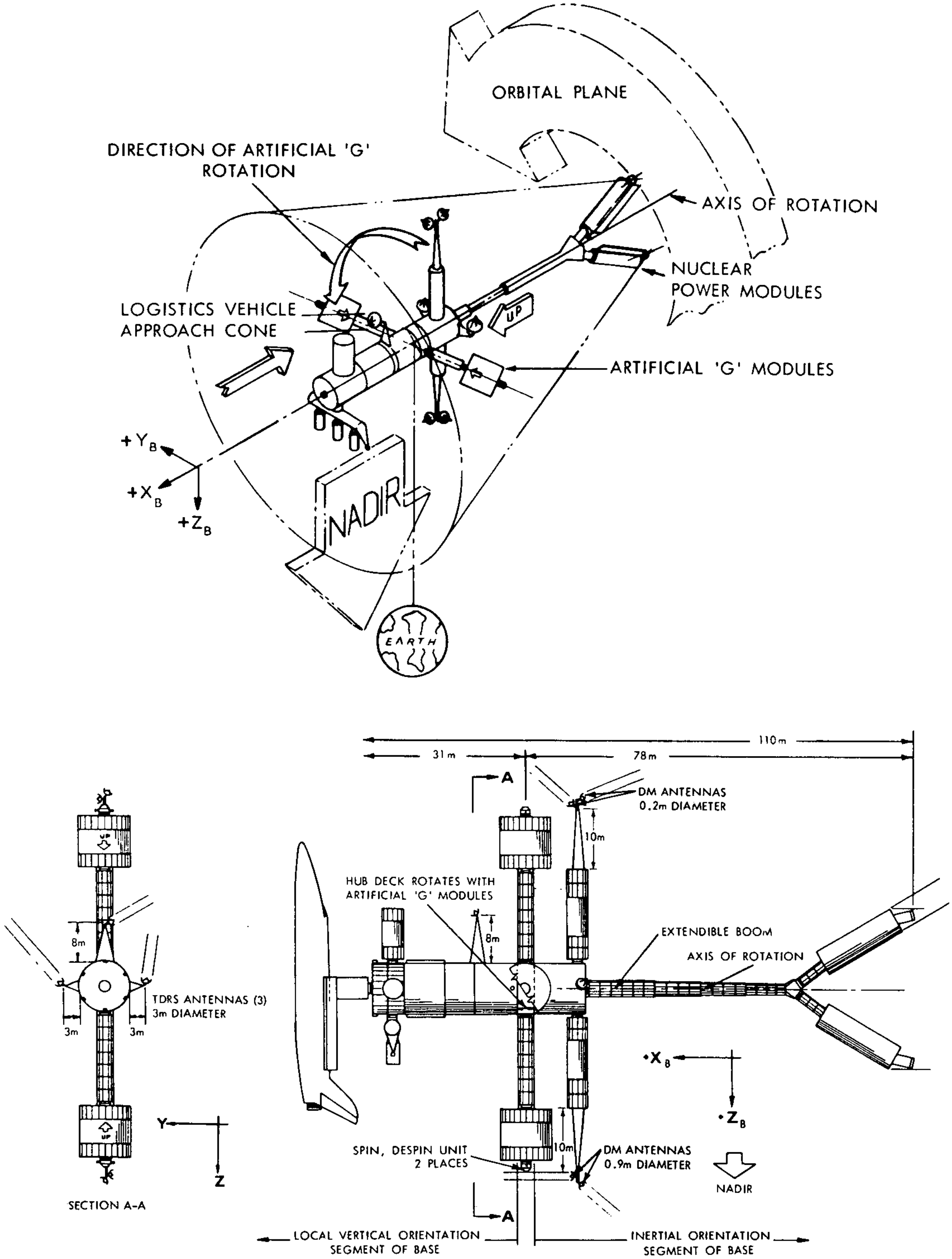


Figure 25. Alternate SB Antenna System for Communication with TDRS and DMs

the TDRS antenna. The aperture size and gain of each array facet is identical to that shown in Figure 23. The phased array configuration in Figure 24 is recommended for the upper segment DM communication link.

If the TDRS antenna is not mounted on the AM, two 0.2 m gimballed reflectors mounted on an extension to the AM would provide hemispherical coverage for the upper segment DM requirement. This reduces the gain and field of view required for the lower segment antennas, which now must provide only hemispherical coverage. Two 0.9 m gimballed reflectors mounted on the AM extending along the +Z axis (Figure 25) will satisfy this lower segment gain and field of view requirement.

C. Advanced Development

The brief tradeoff between corporate fed phased arrays and gimbaled reflectors clearly indicates that conventional phased array techniques are impractical at Ku-band. The only phased array concept that appears promising at this time is the reflectarray. Considering the lead time available for SB hardware, further R&D into reflectarray elements to minimize weight and power consumption is recommended.

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